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ORIGINAL ARTICLE

Segmentation influences learning: a study of knowledge acquisition through virtual reality and 2D video with airport security screeners

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Abstract

Immersive virtual reality (VR) learning bears the potential to enhance outcomes by allowing users to experience virtual scenarios as if they were there. At the same time, multimedia learning literature recommends breaking information into meaningful, learner-paced segments rather than presenting learning content continuously. Despite numerous recent studies evaluating VR, essential questions about VR applications in organizational training contexts remain unanswered for practitioners and researchers. This study evaluates critical aspects of learning outcomes, cognitive load, Interest/Enjoyment, and technology acceptance using a 2 × 2 design with media type (2D video vs. head-mounted display VR) and segmentation (continuous vs. segmented) as between-subjects factors, alongside a control group (without training; to evaluate the effectiveness of the training). The study includes data from 162 airport security screeners. Each experimental condition experienced a multimedia lesson with high contextual relevance and adherence to current instructional design and multimedia theories. Data on post-training Objective Knowledge indicate a significant main effect of segmentation, favoring continuous presentation. Germane Cognitive Load was rated higher in the 2D video than in the VR conditions. We did not observe significant effects on Interest/Enjoyment or aspects of technology acceptance. The Interest/Enjoyment ratings were high across all experimental conditions and strongly correlated with Perceived Usefulness and Behavioral Intention, consistent with recent findings on technology acceptance for immersive technologies. Overall, this study provides valuable insights into the practical implementation of instructional VR applications and encourages further evaluation of learning applications using current VR technology.

Keywords Virtual reality · 2D video · Multimedia learning · Segmentation · Airport security

1 Introduction

The rapid evolution of multimedia learning technologies, especially immersive virtual reality (VR), promises improvements in education and training across many disciplines and professions (e.g., Ahir et al. 2020; Checa and Bustillo 2020; Howard and Gutworth 2020; Xie et al. 2021; Smutny 2023). In the process of developing new learning content, practitioners must determine the most appropriate media type. From a practical perspective, the choice is often between traditional e-learning (e.g., computer-generated multimedia video) and immersive technologies (e.g., immersive VR). Traditional e-learning media (Clark and Mayer 2024), characterized as no immersion or low immersion, utilizes two-dimensional (2D) screen displays (Mayer et al. 2023), such as computer screens or notebooks, with a computer mouse used as input modality. A widespread form of immersive VR uses head-mounted displays (HMD VR) that enable users to perceive the environment stereoscopically, facilitating spatial perception and allowing them to look around freely in the virtual environment (Jerald 2016; Wohlgenannt et al. 2020). With current HMD VR technology, a common way to interact is with tracked handheld VR

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controllers using natural gestures (e.g., in the form of mid-air touch interactions; Luong et al. 2023).

When it comes to how content is presented for multimedia learning, instructional designers and developers often rely on the widely accepted instructional design principles of the cognitive theory of multimedia learning (CTML; for an overview, see Mayer 2021), which were developed for—and mostly validated with—traditional computer-based learning technology (Mutlu-Bayraktar et al. 2019). With the increasing prevalence of HMD VR in the consumer market, researchers highlight the importance of applying these principles to learning applications with immersive VR (e.g., Mulders et al. 2020; Miguel-Alonso et al. 2023). However, it remains largely unclear whether they apply similarly to current HMD VR (Çeken and Taşkın 2022), where narrations often include transient information (instructional animations or spoken text; cf., transient information effect, Wong et al. 2012). Knowledge can be delivered without a break, or users can set their own pace and control short learning sequences. Appropriately segmented learning content (meaningful, coherent, and adequately sized chunks) can be individually paced at the user's desired learning rate (segmenting principle; Mayer and Fiorella 2021; see Chapter 1.2).

Numerous previous studies have addressed VR compared to other media (e.g., Makransky et al. 2021) and segmentation (e.g., Klingenberg et al. 2022) for the educational sector (for systematic reviews on education, see, Radianti et al. 2020; Wu et al. 2020; Di Natale et al. 2020; Pellas et al. 2021; Yu 2021; Hamilton et al. 2021; Villena-Taranilla et al. 2022; Coban et al. 2022; Rojas-Sánchez et al. 2023). Apart from the increasing number of recent studies on the use of VR in the health sector (e.g., on medical emergency simulations: Lerner et al. 2020; on childbirth nursing: Chang et al. 2022) and systematic reviews in this field (e.g., for surgical training: Mao et al. 2021; for medical education and clinical care: Dhar et al. 2023; for nursing: Efendi et al. 2023; Liu et al. 2023), however, there is less empirical research on effectiveness and psychological aspects (e.g., cognitive load, motivation, and technology acceptance) in other organizational and occupational contexts (for simulations in biotech industry: Baceviciute et al. 2022). Several studies emphasize the added value of VR and refer to applications and training scenarios that would be impractical and expensive to implement in reality (e.g., emergency evacuation of an aircraft: Buttussi and Chittaro 2018; fire safety training: Morélot et al. 2021; Lovreglio et al. 2021; Katz et al. 2023; systematic reviews of safety training: Stefan et al. 2023; Sudiarno et al. 2024).

One application that could benefit from modern multimedia learning technologies is the training of airport security screeners. As in many other industries, airports and security service providers face the challenge of simultaneously providing effective, efficient, and motivating training to their employees. For example, the ongoing transition from conventional X-ray to 3D computed tomography (3D CT) technology for cabin baggage screening (Schwaninger and Merks 2019; Smith and Connelly 2022; Vukadinovic and Anderson 2022, p. 21; Cordova 2022, pp. 155–156 [referring to as carry-on baggage]) involves delivering factual, conceptual, and procedural knowledge. Besides conducting image interpretation (by analyzing passengers' screened bags for prohibited items), airport security screeners are also responsible for assisting passengers with divesting, performing alarm resolution of the walk-through metal detector or body scanner, and conducting secondary bag searches (cf. Michel et al. 2014a). To perform these tasks effectively and to respond to passenger questions competently, it is vital that they possess a comprehensive understanding of the regulations, processes, and technologies involved (for e-learning providers, see, e.g., Airports Council International 2024; International Air Transport Association 2024; International Civil Aviation Organization 2024). To learn about new screening technologies, the physical presence of the new 3D CT machines helps contextualize the training content. However, these expensive machines are often difficult to access due to the daily operations of airports. Virtual environments with realistic digital 3D models of spatial settings, machinery, or devices (for details on visual realism, refer to Christou and Parker 1995; for a framework of fidelity, see Ragan et al. 2015; Chapter 1.1) permit the provision of alternative learning experiences, thereby reducing the need for physical infrastructure (e.g., Kamińska et al. 2019; Soliman et al. 2021; Kaplan et al. 2021). To our knowledge, there is no study evaluating HMD VR compared to other training media for airport security.

The possibilities offered by new learning technologies raise questions for both organizational practice and scientific research: Is using immersive HMD VR to obtain new knowledge worth the effort? Should learning content be presented continuously or segmented? In this study, we evaluated the potential benefits of immersive HMD VR compared to conventional 2D screen videos for training airport security screeners. We also assessed how the content should be presented to learners: as a continuous system-paced lesson or segmented into meaningful chunks, paced by the learner. We examined the effects of media type (2D video vs. HMD VR) and segmentation (continuous vs. segmented) on the following dependent variables: post-training Objective Knowledge, Subjective Knowledge Gain, cognitive load (CL), Interest/Enjoyment, and technology acceptance.

1.1 Media type (2D video vs. HMD VR)

The two media types evaluated in the current study (2D video vs. HMD VR) differ in several characteristics that can be classified from different perspectives: from a technological point of view (in terms of hardware, software, and their interplay, which contribute to fidelities: Ragan et al. 2015), from a user experience standpoint (Kim et al. 2020), and from a psychological perception angle (e.g., presence; Slater 2009, 2018; Slater et al. 2022).

Ragan et al. (2015, p. 796) identify three types of fidelity depending on the technologies used: interaction fidelity, display fidelity, and scenario fidelity. Concerning interaction fidelity, an essential distinction between the two media types is that HMD VR users can rotate and move their heads in any direction to look around, enabling them to visually explore their virtual surroundings (resulting in a higher interaction fidelity; Ragan et al. 2015). This is not possible for users of 2D video due to their stationary, non-interactive camera position (low interaction fidelity). Regarding display fidelity, an important feature of HMD VR is the stereoscopic display, with different images for each eye providing depth cues (for further details on binocular disparity, please refer to, e.g., Scarfe and Glennerster 2019, p. 532) for virtual objects and environments, thus providing a high display fidelity. In contrast, 2D videos are traditionally presented on monoscopic 2D displays that have low display fidelity. Scenario fidelity is defined "as the objective degree of exactness with which behaviors, rules, and object properties are reproduced in a simulation" (Ragan et al. 2015, p. 796). Interaction fidelity, display fidelity and scenario fidelity determine together the overall level of realism of the simulation (Ragan et al. 2015), which is sometimes referred to as system fidelity (McMahan and Herrera 2016).

Based on the widely accepted definition by Slater (2009), immersion refers to "the objective capabilities of the system" (Slater et al. 2022, p. 6). Thus, a tracked HMD equipped with a stereoscopic display is considered to provide a higher immersion level than a traditional 2D screen display. Depending on the implementation of the VR application, users of HMD VR may experience a feeling of presence. Slater and Wilbur (1997) define presence as "a state of consciousness, the (psychological) sense of being in the virtual environment" (p. 606). The illusion of presence can be divided into place illusion and plausibility illusion (Slater 2003, 2009; Slater and Sanchez-Vives 2016; Slater et al. 2022). Place illusion is described as the feeling of "being there", while plausibility illusion describes the feeling that the events unfolding within the virtual environment are actually happening. The meta-analysis by Cummings and Bailenson (2016) concludes that a high degree of immersion positively affects the experienced presence and that features such as tracking and stereoscopy reinforce this feeling. Newman et al. (2022 [Experiment 1]) compared real, VR, and 2D video experiences. The study concluded with a "preference for real and virtual experiences over watching a video, in terms of feelings of serenity, ratings of enjoyment, a sense of presence, and a sense of immersion" (Newman et al. 2022, pp. 5–6).

1.2 Segmentation (continuous vs. segmented)

Segmentation, also referred to as the segmenting principle or segmenting effect, is based on the notion that "people learn more deeply when a multimedia message is presented in learner-paced segments rather than a continuous unit" (Mayer and Fiorella 2021, p. 249). When learners receive fast and transient system-paced multimedia instruction as a continuous unit, they may not have sufficient time to mentally organize essential words and pictures into a coherent model and integrate this information with their prior knowledge (Rey et al. 2019). As a result, learning performance may be hindered because of high CL (Spanjers et al. 2010). Segmentation allows for pauses between each instructional unit, which can help counteracting the negative effects of transience associated with multimedia lessons by providing learners additional time for cognitive processing before new information is presented (Moreno and Mayer 2007). Instructional material should be structured into meaningful and coherent segments to help learners perceive the multimedia lesson's underlying structure (Spanjers et al. 2010) and segmentation is closely related to controlling the pace of multimedia instruction. Allowing learners to pace the lesson enables them to adapt the pace to their available cognitive resources (e.g., Hasler et al. 2007; Rey et al. 2019). The term learner-paced, or self-paced, is frequently applied to describe situations in which learners can control the pace of a segmented lesson themselves, while the term system-paced is predominantly used for conditions in which the instructional designers predetermine the pace of a segmented lesson (see, Rey et al. 2019, for examples). Due to different modalities and forms of control, the academic literature on segmentation has not consistently used these terms, at times considering system-paced to involve continuous, non-segmented instruction (e.g., Hasler et al. 2007; Mayer and Fiorella 2021). The present study followed the fundamental characteristics of segmentation applied by Mayer and Chandler (2001), comparing a continuous, non-segmented lesson with a segmented lesson in which learners could initiate the next segment by pressing a button.

1.3 Knowledge

An important objective of this study was to evaluate the knowledge gain of airport security screeners using different media and segmentation types. To be effective in practice, training must serve the intended purpose. In our study, the intended purpose of the multimedia lesson was to increase the knowledge about 3D CT technology and cabin baggage screening procedures, which we tested by applying an objective knowledge test after the participants experienced the multimedia lesson using 2D video or HMD VR compared to a control group without such training. We therefore formulated the following hypothesis:

Hypothesis 1 *Learners in the experimental conditions achieve significantly higher Objective Knowledge scores than participants in the control group (without training).*

We did not expect that changes in Objective Knowledge would depend on media type (2D videos and HMD VR) for several reasons. While HMD VR has been shown to enable learning and has found applications in various educational settings (Rojas-Sánchez et al. 2023), there is no clear evidence in recent literature for the superiority of HMD VR on learning outcomes compared to less immersive media for educational purposes such as 2D videos. For example, a meta-analysis by Hamilton et al. (2021) reported that only approximately half of the 29 articles reviewed showed a positive effect on learning when using immersive VR compared to less immersive pedagogical methods (mixed results on learning outcomes are also reported by other systematic reviews, e.g., Jensen and Konradsen 2018; Matovu et al. 2022). Another meta-analysis of Wu et al. (2020) reports a small effect size on learning effectiveness in favor of HMDs compared to non-immersive interventions. However, as Makransky and Petersen (2021) postulate in their Cognitive Affective Model of Immersive Learning (CAMIL), research should differentiate between different knowledge taxonomies to better understand the effect of learning outcomes with VR. Related to this issue, Anderson et al. (2001) provide a valuable framework based on Bloom's taxonomy (Bloom et al. 1956) by dividing knowledge into four dimensions: factual, conceptual, procedural, and metacognitive knowledge. According to Anderson et al. (2001), factual knowledge comprises basic, isolated elements needed in a specific domain to understand and solve problems. Conceptual knowledge encompasses more complex and organized information, such as schemas and mental models, which are structured in a systematic manner. Together, factual and conceptual knowledge represent the "what" of knowledge (Anderson et al. 2001) and are at times combined into declarative knowledge (Makransky and Petersen 2021). Finally, the "how" of knowledge is encompassed in procedural knowledge and includes various procedures and behaviors, such as skills, algorithms, techniques, and methods (Anderson et al. 2001). Recent literature has shown that VR is not particularly effective for factual or conceptual knowledge acquisition. Several studies reported that immersive VR is similar to (e.g., Webster 2016; Makransky et al. 2019a, 2021 [Experiment 1]; Parong and Mayer 2020; Baceviciute et al. 2022) or less effective (e.g., Makransky et al. 2019b, 2021 [Experiment 2]; Parong and Mayer 2021) than non-immersive instructional methods for posterior knowledge tests. Interestingly, Parong and Mayer (2018) found VR to be less effective for acquiring factual knowledge than a slideshow presented on a 2D screen display but not for conceptual knowledge. For procedural knowledge acquisition, similar mixed results have been reported: While some studies reported more effective acquisition with VR (e.g., Li et al. 2017; John et al. 2018), others did not affirm this tendency. For example, Buttussi and Chittaro (2018) report similar knowledge increases after experiencing safety training on a standard desktop monitor vs. with HMD VR–immediately after the experience as well as two weeks later. Also, in a study by Makransky et al. (2021), high school students did not achieve better learning outcomes of procedural knowledge in a science simulation with VR than the video condition on a 2D screen display.

Although prior knowledge has long been considered a positive factor for learning (e.g., Tobias 1994; Dochy et al. 1999; Hailikari et al. 2008; Delgado and Mayer 2025), the literature has shown mixed effects on Subjective Knowledge Gain. For example, some studies found positive effects due to increased presence in immersive VR (Makransky and Lilleholt 2018; Makransky and Klingenberg 2022). However, a study by Makransky et al. (2019b) with university students showed no difference in subjective learning outcomes between a VR and 2D simulation. Furthermore, a study by Han (2020) with elementary school students even found a negative effect of VR on perceived learning compared to less immersive media. One possible explanation lies in a feature of VR: the high interaction fidelity of HMD VR is accompanied by the risk of losing the learner's attention by "moving attention away from the content to irrelevant stimuli in the lesson" (Parong and Mayer 2020, p. 238). Makransky (2021) also highlights "cybersickness, technological challenges, or because the immersive experience distracted from the learning task" (p. 297) as explanations as to why the often-expected better learning outcomes with VR have not always been observed.

Regarding segmentation, studies have consistently shown that segmenting multimedia instruction can enhance learning outcomes (e.g., Boucheix and Guignard 2005; Hasler et al. 2007; Moreno 2007; Mayer et al. 2018). Meta-analyses have confirmed these findings: Rey et al. (2019) reported a small- to medium-sized effect of segmenting for knowledge retention and transfer when the material was segmented by the instructional designers rather than the learners. A systematic review by Çeken and Taşkın (2022) concluded that 71% of the 15 examined studies showed improved learning outcomes when the instructional material was segmented. While a study by Parong and Mayer (2018) suggested that segmentation may also aid learning processes when using VR, two recent studies found no benefit when instructional content was divided into smaller, more manageable segments (Ahn et al. 2022; Klingenberg et al. 2022). Based on the widely accepted findings that segmentation enhances learning outcomes, we formulated the following hypothesis:

Hypothesis 2 *Learners in the continuous conditions achieve significantly lower Objective Knowledge scores than learners experiencing the content in segmented conditions.*

1.4 Cognitive load

The CAMIL (Makransky and Petersen 2021) identifies CL as a principal factor when designing and examining VR for educational purposes, as it provides an understanding of the cognitive demands involved in the learning processes. Cognitive Load Theory (CLT; Sweller et al. 2011) and, similarly, the CTML (Mayer 2021), propose that human cognitive processing is heavily constrained by working memory, inhibiting learning when cognitive processing exceeds the learners' capacity (Sweller et al. 2011, pp. 42–45, 2019, p. 262; Mayer 2021, p. 60). Therefore, managing CL in the learner's experience is essential for successful instruction.

Generally, CL is differentiated into three types (Sweller et al. 1998): Intrinsic Cognitive Load (ICL), Extraneous Cognitive Load (ECL), and Germane Cognitive Load (GCL). Intrinsic Cognitive Load refers to the complexity of the information in the learning material and the knowledge of the person processing that information (Sweller et al. 2019). In order to address the instructional complexity and manage ICL, segmentation may be a viable strategy. Fourteen out of 20 studies analyzed by Rey et al. (2019) indicated that segmentation reduces overall cognitive load (p. 409). Substantiated by the small- to medium-sized effect of segmenting for knowledge gain and transfer (Rey et al. 2019), as well as further literature presented in chapter 1.3, it has been theorized that segmenting the learning material into meaningful chunks, introducing pauses, and allowing learner-controlled pacing may reduce the instructional content's complexity, facilitate the management of ICL and moderately increase learning (e.g., Mayer and Moreno 2010; Noetel et al. 2022). Based on this, we propose the following hypothesis:

Hypothesis 3 *Learners in the continuous conditions report significantly higher ICL scores than learners experiencing the content in segmented conditions.*

Extraneous Cognitive Load is determined by how the learning material is presented and the learner's activities during the instructional task (Sweller et al. 2019). The CLT focuses mainly on techniques to reduce extraneous load, as this allows for more attention to be invested in cognitive processes facilitating learning (Sweller 2010). Previous studies have suggested that VR can lead to increased ECL and, in turn, inhibit learning due to the high amount of sensory information and the ability to freely explore and interact with their surroundings (e.g., Parong and Mayer 2020; Makransky et al. 2021). Concerning segmentation, the literature highlights that increased control and agency may negatively influence ECL if the learner is not familiar with the media's control mechanisms (e.g., Makransky et al. 2019b, 2021; Poupard et al. 2025). Considering this literature and focusing on the interaction fidelity related to HMD VR as well as the interaction to control the progress associated with the segmented conditions, we put forth the following hypotheses:

Hypothesis 4 *Learners in the 2D video conditions report significantly lower ECL scores than learners in the HMD VR conditions.*

Hypothesis 5 *Learners in the continuous conditions report significantly lower ECL scores than learners experiencing the content in segmented conditions.*

Last, GCL emerges during the formation and regulation of mental models and schemata, thereby facilitating learning and contributing to transfer performance (e.g., Paas et al. 2003; Moreno and Park 2010). While the traditional approach to CLT suggests that reducing cognitive load imposed by the instructional content, its delivery along with the learner's activities allows resources to be redirected to germane cognitive processes that facilitate learning, a proposed reconceptualization of CLT departs from the notion of germane load adding to the total load (Sweller et al. 2019; Duran et al. 2022; Krieglstein et al. 2022). Instead, the GCL is assumed to allocate working memory resources to intrinsic aspects of the task to deal with the imposed ICL. While this refined approach has been largely accepted and employed for creating and interpreting CL scales (e.g., Leppink et al. 2013, 2014), some researchers have remained committed to the original concept, arguing that it facilitates understanding instructional design effects (e.g., Klepsch and Seufert 2020). In the present study, we assessed the three types of CL using two different scales for each type. The items and latent construct behind the instrument by Klepsch et al. (2017) are rooted in the traditional understanding of GCL, while the scale by Leppink et al. (2014) assumes a reconceptualized characterization. At the same time, both approaches claim to differentiate between the three types of CL, Klepsch and Seufert (2020) state "that the questionnaire still must be validated in different and more ecologically valid learning contexts" (p. 50). By comparing the two instruments exploratorily in our study, we aim to contribute to the broader discourse on the different instruments measuring CL. Considering the novel interpretation and scarce empiric evaluations of GCL with the instrument by Leppink et al. (2014), we propose the following hypothesis based on the traditional understanding of CL (Klepsch et al. 2017):

Hypothesis 6 *Learners in the 2D video groups report significantly higher GCL scores than learners in the HMD VR groups.*

Based on the traditional understanding of CL (Klepsch et al. 2017) and assuming that the segmented conditions reduce ICL due to less instructional complexity, learners should be able to invest more attention in cognitive processes resulting in higher GCL in the segmented conditions compared to the continuous conditions. This led to the following hypothesis:

Hypothesis 7 *Learners in continuous conditions report significantly lower GCL scores than learners experiencing content in segmented conditions.*

In the absence of established literature, we do not propose a hypothesis on the comparability of the instruments by Leppink et al. (2014) and Klepsch et al. (2017). Instead, we approach this comparison exploratorily to shed light on an under-researched area and contribute to the broader discourse on subjective CL instruments.

1.5 Interest/Enjoyment

Affective factors such as intrinsic motivation have been recognized as crucial elements of learning with immersive media (Makransky and Petersen 2021). Interest and enjoyment are considered central aspects of intrinsic motivation. Building on the Self-Determination Theory (Ryan and Deci 2017), intrinsic motivation is experienced when one engages in an activity for its inherent satisfaction, as opposed to external rewards or pressures. However, for this to occur, an activity must be of intrinsic interest, appear novel or challenging, or have aesthetic value to the learner (Ryan and Deci 2017). Furthermore, intrinsic motivation involves both personal and situational interests (Linnenbrink and Pintrich 2002). For learning with VR, this means that both the learning content and the learning activity are important. While intrinsic motivation has been shown to play a significant role in school achievement (Taylor et al. 2014; Froiland and Worrell 2016), Ryan and Deci (2017) argue that intrinsic motivation may be responsible for the preponderance of human learning across the lifespan.

Compared to less immersive media, VR can lead to higher intrinsic motivation (e.g., Makransky et al. 2019a, comparing text to desktop VR and HMD VR; Zhao et al. 2020, comparing interactive video and HMD VR; Makransky and Klingenberg 2022, comparing personal trainer and HMD VR). Several studies reported HMD VR's superiority over 2D screen displays (e.g., Meyer et al. 2019; Klingenberg et al. 2020, after participants experienced both media types; Makransky et al. 2021). Based on this research, we formed the following hypothesis:

Hypothesis 8 *Learners in the 2D video conditions report significantly lower Interest/Enjoyment scores than learners in the HMD VR conditions.*

Only a few studies have focused on aspects of segmentation regarding Interest/Enjoyment (e.g., Moreno 2007; Mayer et al. 2018; Parong and Mayer 2018). Because no clear evidence was reported, we did not formulate a hypothesis on effects of segmentation on Interest/Enjoyment.

1.6 Technology acceptance

In addition to learning outcomes (Chapter 1.3), cognitive aspects (Chapter 1.4), and affective (Chapter 1.5) aspects, learners' technology acceptance is a fourth important factor for the success of a multimedia learning system. The Technology Acceptance Model (TAM; Davis 1989) was developed to prognosticate the use of information technology. According to the TAM, Perceived Usefulness (PU) and Perceived Ease Of Use (PEOU) impact Behavioral Intention (BI), which predicts actual use. In addition to the proven validation and widespread application of the TAM in educational contexts (e.g., Granić and Marangunić 2019), the meta-analysis by Šumak et al. (2011) supports the TAM for training in organizational contexts. In the last two decades, various developments and extensions of the original model have evolved (e.g., TAM2: Venkatesh and Davis 2000; Unified Theory of Acceptance and Use of Technology: Venkatesh et al. 2003; TAM3: Venkatesh and Bala 2008), some even with a specific focus on evaluating immersive technologies (e.g., Manis and Choi 2019; Sagnier et al. 2020; Fussell and Truong 2022; Oyman et al. 2022; Villena-Taranilla et al. 2023). These extended models and other publications investigating novel technologies with TAM (cf., Shamy and Hassanein 2017; Lee et al. 2019; Jimenez et al. 2021) emphasize that enjoyment is strongly related to PU and BI. Based on the mentioned literature, we formulated the following hypotheses:

Hypothesis 9a *Interest/Enjoyment correlates with PU for 2D video.*

Hypothesis 9b *Interest/Enjoyment correlates with PU for HMD VR.*

Hypothesis 10a *Interest/Enjoyment correlates with BI for 2D video.*

Hypothesis 10b *Interest/Enjoyment correlates with BI for HMD VR.*

To our knowledge, publications comparing learning technologies based on the core aspects of the TAM are scarce for media types and nonexistent for segmentation. A point of reference on media type is the study by Sprenger and Schwaninger (2021), who compared the use of independent e-lectures and cardboard-based VR learning sessions (among other technologies) in a higher education setting. The use of VR yielded lower acceptance scores in PU, PEOU, and BI than in e-lectures. However, because this study compared different learning content and usage times, its comparability with the present study is limited.

1.7 Current study

As discussed in the previous sections, questions remain unanswered for practitioners and researchers regarding the implementation of multimedia lessons. Despite the numerous publications on immersive VR, to our knowledge, the present study is the first to systematically compare advanced media and segmentation types of a multimedia learning application in a practical organizational setting, accounting for learning outcomes, cognitive and affective aspects, and learner technology acceptance. We used a 2 × 2 study design with the independent variables (IVs) media type (IV 1: 2D video vs. HMD VR) and segmentation (IV 2: continuous vs. segmented). For this purpose, we designed and implemented a multimedia lesson with high contextual relevance (3D CT technology and processes for airport security baggage screening), following state-of-the-art instructional design theory (Morrison et al. 2019) and design principles based on multimedia theory (Mayer and Fiorella 2021).

2 Method

2.1 Participants

We determined the number of participants for the four experimental groups based on an a priori power analysis using G*Power (Faul et al. 2007). Specifically, we conducted a power analysis for a between-subjects ANOVA with four groups, alpha error = 0.05, power = 0.80, and a medium effect size (f = 0.25). This analysis focused on Hypotheses 2 to 8, which involved a 2 × 2 between-subjects design. The participants were recruited at an international airport with the following inclusion criteria: working as security screeners, having no prior 3D CT screening experience, and voluntary participation. Considering availability and shift scheduling, the airport randomly selected 163 participants from this pool. One person's data were excluded from the analysis, as the computer performed an unexpected restart during the training session (continuous 2D video group). The remaining participants' ($n = 162$) mean age was 45.53 years ($SD = 10.12$), and their mean work experience was 11.22 years ($SD = 8.40$). Of the participants, 66 were female (41%), 96 were male (59%), and no one identified as other (0%). Furthermore, less than a third (30%) of the participants had experienced VR before participating in this study.

Participants were informed of the objectives and study procedures prior to the study. Written informed consent was obtained from all participants. No additional monetary compensation was provided, as the study took place during their regular working hours. All screeners were qualified, trained, and certified according to the standards set by the appropriate national authority (civil aviation administration) in compliance with the related EU regulation (European Commission 2015) for cabin baggage screening.

2.2 Experimental design, conditions, and apparatus

We applied a 2 × 2 between-subjects design, with media type (2D video vs. HMD VR) and segmentation (continuous vs. segmented) as IVs, leading to four experimental groups experiencing the multimedia lesson with uniform learning content: continuous 2D video, segmented 2D video, continuous HMD VR, and segmented HMD VR. We also included a control group to compare to a knowledge baseline (without undergoing training; cf., Michel et al. 2014b; Bertram et al. 2015).

To allow for comparability of the 2D video and HMD VR conditions, we did not implement complex interactions (e.g., active exploration of 3D objects with a computer mouse or VR controller). The visual (including 3D models, 3D environment, and animations) and auditory learning content

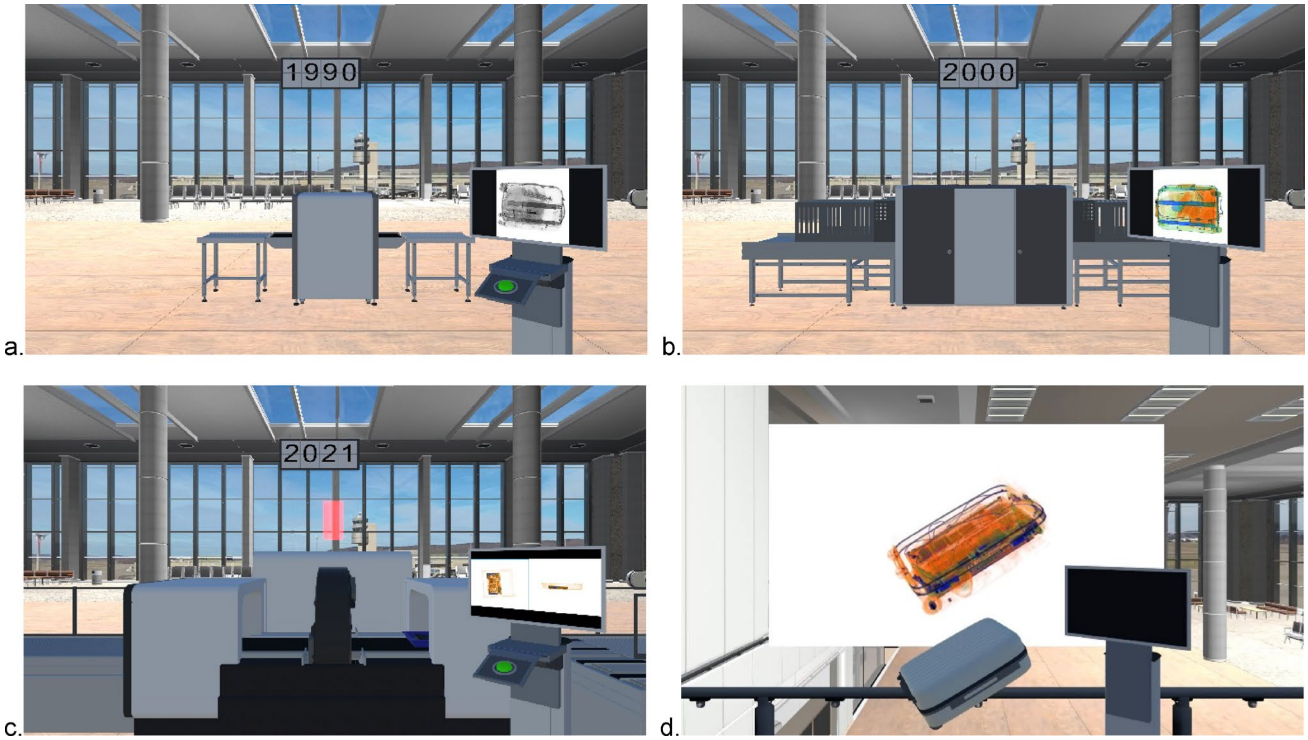

Fig. 1 Screenshots of the multimedia lesson (view for 2D video, identical to the front view for HMD VR). **a** A generic X-ray machine of the 1990s. **b** A generic X-ray machine of the 2000s. **c** Animated inner workings of a generic 3D CT machine. **d** A 3D-modeled suitcase with a corresponding 3D CT image

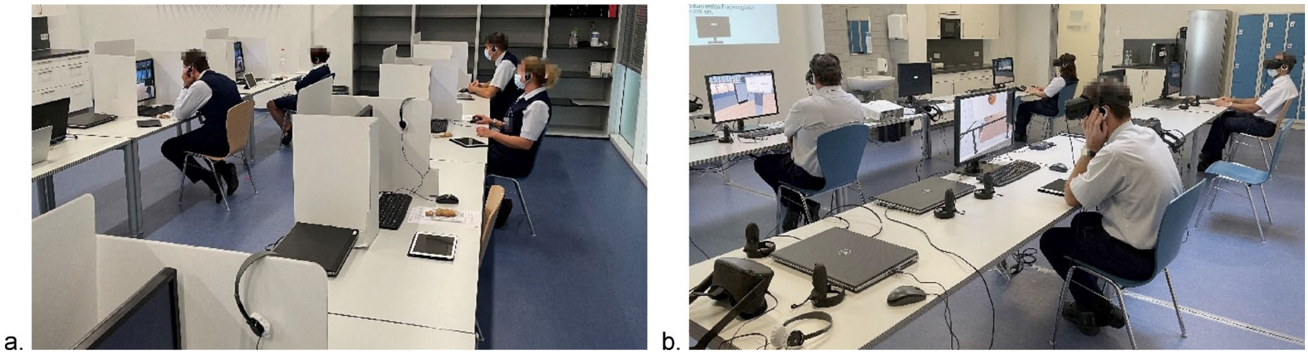

Fig. 2 Settings of the data collection at an international airport with experienced X-ray cabin baggage screeners. **a** Screeners experiencing the training as a video on a 2D screen display. **b** Screeners experiencing training in VR

(narrative content via on-ear headphones: JVC HA-L50) were identical for all four experimental conditions. In the continuous 2D video condition, the participants viewed the learning content as a video on a 2D screen (task type: watching; Kim et al. 2020). In the segmented 2D video condition, the participants used a computer mouse to control the pace of the segmented learning experience (task type: system control; Kim et al. 2020), stationary camera position (world-fixed type; Kim et al. 2020, p. 896; low interaction fidelity), directed at relevant learning content (primary action; Pirker et al. 2020, pp. 323ff) in front of the viewer (for examples, see Fig. 1). The compiled application with the multimedia lesson was run on performant notebooks (Dell Mobile Precision 7720, equipped with an Intel i7-7700HQ processor, NVIDIA Quadro P4000 graphics processing unit, 16-gigabyte random access memory, running on 64-bit Windows 10) and displayed on 24-inch LCD monitors (resolution: 1920 × 1200 pixels; Samsung LS24E65KBWV/EN) placed on a desk fitted with a cardboard visual cover to reduce visual distractions (Fig. 2a).

Similarly, the learning content was centered in front of the viewer for the HMD VR groups. However, the six degrees of freedom (6DOF) HMD (non-see through, assembled HMD; Kim et al. 2020, p. 896) offered a more immersive experience, allowing users to look around freely (high interaction fidelity; limited due to the sitting posture; Kim et al. 2020, p. 898) and explore the virtual surrounding. The learning experience was administered with first-generation Oculus Quest HMDs (resolution per display: 1440 × 1600 pixels) tethered to a VR-capable notebook (Dell Mobile Precision 7740, equipped with an Intel i7-9850H processor, NVIDIA Quadro RTX 5000 graphics processing unit, 32-gigabyte of random access memory, running on 64-bit Windows 10) in Oculus Link mode, which ran the compiled VR applications (Fig. 2b).

Regarding segmentation, the two participant groups in the continuous conditions did not control progress; their multimedia lesson progressed without human–machine interaction (non-interactive, apart from the 6DOF view orientation with the HMD VR groups) and ran continuously until the end of the instructional content (Fig. 1b, d). Accordingly, no purposeful pauses were used to separate thematic chapters of the instructional material. In contrast, the two segmented groups manually started each segment by pressing a then-illuminated button. This allowed participants to control the pace of the learning segments and reflect on smaller chunks of the information before continuing the instruction when they felt ready (in line with Moreno 2007). To advance to the next learning segment, participants in the segmented 2D video condition clicked the illuminated green button (Fig. 1a, c) using a standard wired computer mouse as the input device. The mouse pointer was visible only when the button was active, not to distract from the instructional material. To advance to the next learning segment, participants in the segmented VR HMD condition had to touch the green button in the 3D environment (placed within arm's reach; cf., mid-air touch interaction, Luong et al. 2023) using a 6DOF VR controller (tracked handheld controller; Kim et al. 2020, p. 896; second-generation Oculus Touch, corresponding to their handedness). Following the concept of the 2D video conditions, the visual representation of the VR controller in the HMD VR conditions (cf. Lougiakis et al. 2020; Seinfeld et al. 2021) was only visible when the users could press the button; it was invisible at all other times.

2.3 Training material

The multimedia lesson was developed specifically for the current study, incorporating the instructional design principles of the CTML (Mayer 2021) to manage CL. The learning experience (single user; Kim et al. 2020, p. 897) was implemented using the game engine Unity version 2020.3.19f1 (Unity 2021) and compiled as Windows executables for each of the four experimental conditions.

The multimedia lesson started with an introduction explaining the lesson's aim and allowing the participants to acclimate themselves to the experimental conditions. This was followed by three thematic chapters divided into a total of 14 segments with learning content (total duration for the continuous conditions: 10 min and 45 s; Table 2). The instructional materials, which were designed to be narrative in nature (cf., Matovu et al. 2022; Calvert and Hume 2023), focused on providing novel and experienced 2D X-ray screeners with introductory information about 3D CT imaging systems (Fig. 1). Referring to Anderson et al.'s (2001) revision of Bloom's taxonomy, the learning material contained primarily factual knowledge (e.g., "The 3D CT machine you see in front of you meets the C3 standard of the European Civil Aviation Conference"), conceptual knowledge (e.g., "this means that liquids and laptops can be left in baggage for the scanning process"), and procedural knowledge (e.g., "with the possibility to rotate the object, the identification of this object becomes much easier. In this case, the rotation clearly shows that the object is a pepper spray prohibited in hand luggage").

2.4 Procedure

The study took place at the airport's facilities. After receiving a short oral briefing, participants were randomly assigned to one of five groups (2D video continuous, 2D video segmented, HMD VR continuous, HMD VR segmented, control group). Participants were tested in groups of up to six persons in the same room (usually four or five). The study rooms were similar in terms of their layout, furniture, and lighting and were located away from potential disturbances caused by airport operations (Fig. 2).

All participants completed a pre-training survey using an iPad, with items on demographics and Preknowledge. Next, participants of the four experimental groups received verbal information and instructions about the study procedure. Before starting the multimedia lesson, the HMD VR groups were shown how to use the VR equipment correctly. This included ensuring a comfortable fit of the HMD and adjusting the pupillary distance of the HMD lenses. Participants who experienced the content in the segmented HMD VR condition were also shown how to hold the VR controller properly. Participants experienced the multimedia lesson in a seated position. The audio (instructional content and selected sound effects) was delivered through headphones, with the volume set equally for all participants. Once the instructors individually checked for overall readiness and the participants verbally confirmed that they were ready to begin, the instructors started the learning content individually for each participant by pressing a designated key on the keyboard. The post-training survey was administered immediately after finishing the multimedia lesson using an iPad.

Participants in the control group completed only the pre-training survey and the Objective Knowledge assessment (baseline). Afterward, they were also given the opportunity to experience the multimedia lesson, but this data was not analyzed.

2.5 Measures

All participants first completed a survey on demographics (gender, age, work, and VR experience) and Preknowledge. Preknowledge was assessed by three items on participants' self-rated prior knowledge of 3D CT screening technology, analogous to Moreno and Mayer (1999). The post-training survey consisted of measures assessing simulator sickness, Subjective Knowledge Gain, Objective Knowledge, CL, intrinsic motivation, and technology acceptance. To adequately assess simulator sickness (also called cybersickness; Rebenitsch and Owen 2016), we formulated a yes/no item (corresponding to Chang et al. 2021) and asked the participants to describe the discomfort if they answered in the affirmative (open question). This allowed a more accurate description of the temporal characteristics of experienced simulator sickness symptoms. Subjective Knowledge Gain was measured using the corresponding 3-item scale by Ritzmann et al. (2014) with a reported reliability of 0.81 (p. 50). Participants rated Subjective Knowledge Gain before the Objective Knowledge measure to avoid distorting the self-reported learning effectiveness. Objective Knowledge was measured with ten self-constructed multiple-choice items (each with one correct and three incorrect options) that asked mainly for declarative knowledge (similarly to Makransky et al. 2019b). For each item, only one option could be selected. The two CL scales applied in this study by Leppink et al. (2014) and Klepsch et al. (2017) discriminate between three types of CL: ICL ("determined by both the complexity of the information and the knowledge of the person processing that information" Sweller et al. 2019, p. 264), ECL ("how the information is presented and what the learner is required to do by the instructional procedure" Sweller et al. 2019, p. 264), and GCL ("productive load that helps with schema acquisition and automation" Klepsch and Seufert 2020, p. 48). However, the instruments differ in their understanding of how germane cognitive processes influence learning (Klepsch et al. 2017; Klepsch and Seufert 2020). Leppink et al. (2014, p. 1065) reported Cronbach's α values of 0.81 for ICL (3 items), 0.85 for ECL (3 items), and 0.91 for GCL (4 items), while Klepsch et al. (2017, p. 12) reported reliabilities of 0.81 for ICL (2 items), 0.86 for ECL (3 items), and 0.67 for GCL (3 items). The order of the two CL scales was randomly assigned (balanced; see Appendix for all items). For Interest/Enjoyment, we used the corresponding subscale of the Intrinsic Motivation Inventory (IMI). The IMI is rooted in a publication by Ryan (1982) and has since been validated and improved in subsequent studies (Ryan et al. 1983, 1990, 1991; Plant and Ryan 1985; McAuley et al. 1989, 1991; Deci et al. 1994). The interest and enjoyment subscale used in this study is considered the self-reported measure of intrinsic motivation (Cortright et al. 2013; Mekler et al. 2014) and consists of seven items (McAuley et al. 1991, p. 145 [with reported reliability of 0.92]). Technology acceptance was evaluated with the core scales of the revised and latest version of the established authors (TAM3; Venkatesh and Bala 2008): PU (4 items), PEOU (4 items), and BI (3 items), which report internal consistency reliabilities after initial technology use of 0.92, 0.93, and 0.90, respectively (Venkatesh and Bala 2008, p. 287 [after initial training]).

Except for simulator sickness and Objective Knowledge, all scales were rated on a seven-point Likert scale ranging from (1) strongly disagree to (7) strongly agree. All survey items were administered in German (see Appendix). Some items were slightly reworded (e.g., "task" was changed to "learning task"), were translated from existing items if no German version was available (following the procedure suggested in Beaton et al. 2000), and the tense was changed where needed.

2.6 Statistical analyses

To examine the psychometric and descriptive statistics, analyses of variance (ANOVAs), chi-square (χ^2) tests, correlations, and *t*-tests, we used the free and open statistical software JAMOVI version 2.3.19.0 (The jamovi project 2022), with alpha set to 0.05. To adjust for multiple *t*-tests, we used the Bonferroni-Holm correction (Holm 1979). Effect sizes of ANOVAs are reported using partial eta-squared ($\eta^2 p$) and interpreted with 0.01, 0.06, and 0.14 as small, medium, and large effects, respectively (Cohen 1988, p. 368). Correlation coefficients (r, r_s) higher than 0.10 are interpreted as small, those higher than 0.30 are interpreted as medium, and those higher than 0.50 are interpreted as strong effects (Cohen 1988, pp. 79–80).

3 Results

We analyzed the data of 162 participants (as mentioned above, the data of one participant had to be excluded from the analysis because the computer performed an unexpected restart during the training session). The groups of the two-way ANOVAs include 32 screeners in each of the continuous 2D video ($n=32$) and segmented 2D video ($n=32$)

groups and 33 screeners in each of the continuous HMD VR ($n = 33$) and segmented HMD VR ($n = 33$) groups. Additionally, 32 screeners were assigned to the control group ($n = 32$). The participants for each group remained the same for all analyses. No outliers were detected in or removed from the data.

3.1 Psychometrics

Table 1 shows the psychometrics of the scales applied in this study: 10 scales showed acceptable to very good reliability based on the recommendations for psychometrics of DeVellis and Thorpe (2022, p. 130). An ECL scale (4 items; Leppink et al. 2014) and a GCL scale (3 items; Klepsch et al. 2017) computed a low Cronbach's α value; DeVellis and Thorpe (2022) consider it undesirable (0.60 to 0.65). The TAM PU scale (4 items; Venkatesh and Bala 2008) yielded a very high Cronbach's α value, for which DeVellis and Thorpe (2022) would encourage shortening the scale due to potential redundancies. The reliability of our Objective Knowledge assessment (10 distinct multiple-choice knowledge items, difficulty index ranging from 0.20 to 0.94) was low in terms of internal consistency. We selected these 10 items with different knowledge types and training topics from a larger question pool evaluated in a pilot study. We expected a low internal consistency when applying diverse knowledge items that typically do not measure the same underlying construct (Taber 2018). Considering this and the widespread utilization of the aforementioned three scales in their original form, we did not modify the constructs or shorten individual items for the analysis.

3.2 Control variables

Before addressing the research questions, we examined whether the groups differed in demographics, experience, and prior knowledge using one-way between-subjects ANOVAs. We did not find significant differences between the five participant groups (four experimental groups and one control group) regarding age, $F(4, 157) = 0.03$, $p = 0.998$, years of CBS working experience $F(4, 157) = 0.78$, $p = 0.544$, average hours per month worked in CBS $F(4, 157) = 0.58$, $p = 0.679$, or Preknowledge of 3D CT technology $F(4, 157) = 0.42$, $p = 0.791$. χ^2 tests yielded no significant differences between the five groups regarding the proportion of men and women, $\chi^2(4, n = 162) = 2.48$, $p = 0.649$, or experience with VR, $\chi^2(4, n = 162) = 6.76$, $p = 0.149$. Five persons reported a sense of discomfort after the multimedia lesson. However, this aspect did not differ between the experimental groups, $\chi^2(3, n = 130) = 3.86$, $p = 0.276$.

We also inspected the time spent by the participants to finish the lesson (Table 2). As expected, participants in the segmented conditions took more time to complete the learning content than in the continuous condition (all $ps < 0.001$; *t*-tests, one-tailed) and for each of the relevant content segments (segment 1 to 13; for 2D video groups, all $ps < 0.001$; for HMD VR groups, all $ps < 0.05$; *t*-tests, one-tailed).

3.3 Effects of media type and segmentation on knowledge

To evaluate the effectiveness of the training, we first examined whether the multimedia lesson affected Objective Knowledge after experiencing it. A one-way ANOVA revealed a significant difference between the groups: $F(4, 157) = 5.55$, $p < 0.001$. Compared to the control group

Table 1 Psychometric properties for the scales and subscales

Scales	*n*	*M*	*SD*	Cronbach's α
Preknowledge (analogous to Moreno and Mayer 1999, p. 361)	162	2.54	1.49	0.85
Objective Knowledge (10 items, correct [1]/incorrect [0]; max. sum-score: 10)	162	5.81	1.73	0.33[1]
Subjective Knowledge Gain (3 items; Ritzmann et al. 2014)	130	5.48	1.21	0.89
CL, each subconstruct measured with two scales				
ICL (4 items; Leppink et al. 2014)	130	3.47	1.35	0.89
ICL (2 items; Klepsch et al. 2017)	130	3.49	1.42	0.78
ECL (4 items; Leppink et al. 2014)	130	1.74	0.82	0.65
ECL (3 items; Klepsch et al. 2017)	130	2.31	1.17	0.86
GCL (5 items; Leppink et al. 2014)	130	4.95	1.05	0.82
GCL (3 items; Klepsch et al. 2017)	130	4.75	1.24	0.63
Interest/Enjoyment (7 items; McAuley et al. 1991)	130	5.96	0.81	0.73
TAM				
PU (4 items; Venkatesh and Bala 2008)	130	5.60	1.36	0.96
PEOU (4 items; Venkatesh and Bala 2008)	130	5.91	1.11	0.82
BI (3 items; Venkatesh and Bala 2008)	130	5.93	1.31	0.83

[1] Due to the dichotomous nature of the data, the computation is equivalent to the KR20 formula

CL, cognitive load; ICL, Intrinsic Cognitive Load; ECL, Extraneous Cognitive Load; GCL, Germane Cognitive Load; TAM, Technology Acceptance Model; PU, Perceived Usefulness; PEOU, Perceived Ease of Use; BI, Behavioral Intention (without training; $M = 4.72$, $SD = 1.73$), all experimental groups achieved significantly higher scores (all $ps < 0.05$; *t*-tests, one-tailed).

We then explored the impact of the two IVs (media type, segmentation) on post-training Objective Knowledge for the experimental groups with a two-way between-subjects ANOVA. While these ratings did not depend on the media type, we found a significant main effect for segmentation on Objective Knowledge (Table 3). Participants experiencing a continuous multimedia lesson achieved better Objective Knowledge scores ($M = 6.40$, $SD = 1.60$) than the segmented groups ($M = 5.75$, $SD = 1.61$). The ANOVA yielded no significant interaction between media type and segmentation. No significant main or interaction effects were found for the Subjective Knowledge Gain scale.

3.4 Effects of media type and segmentation on cognitive load

We examined the effects of media type and segmentation on all three types of CLs (ICL, ECL, GCL) by two-way between-subjects ANOVAs (Table 4) using the measures from Leppink et al. (2014) and Klepsch et al. (2017). While no significant main or interaction effects were yielded for ICL and ECL, the media type showed a main effect for both measures applied for GCL. For the measure of Leppink et al. (2014), participants in the 2D video groups (low interaction and display fidelity; $M = 5.15$, $SD = 0.93$) reported higher GCL than those in the HMD VR groups (high interaction and display fidelity; $M = 4.75$, $SD = 1.12$). Similarly, participants experiencing the content as a 2D video rated the GCL measure of Klepsch et al. (2017) higher ($M = 4.97$, $SD = 1.14$) than participants using HMD VR ($M = 4.53$, $SD = 1.31$). No significant main effect on segmentation or interactions between media type and segmentation was found for either GCL scale.

To gain a better understanding of the two CL measures, we also examined the correlations for each of the corresponding measures from Leppink et al. (2014) and Klepsch et al. (2017). For all three aspects of CL, the measure pairs correlated positively: strong for ICL, $r(128) = 0.61$, moderate for ECL, $r(128) = 0.46$, and strong for GCL, $r(128) = 0.53$ (all $ps < 0.001$).

3.5 Effects of media type and segmentation on interest/enjoyment

Considering the seven-point Likert scale, the participants of all groups generally rated the Interest/Enjoyment scale high (ranging from $M = 5.87$ to $M = 6.12$; Table 5). No significant main effects or interactions between media type and segmentation were observed.

Table 2 Durations of the learning unit and individual segments in seconds

	Continuous				Segmented			
	2D video		HMD VR		2D video		HMD VR	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Introduction	27.21	0.01	95.98	13.68	77.66	2.13	127.65	9.64
Learning content	644.53	0.05	644.70	0.05	700.42	7.75	701.25	24.45
Segment 1	38.20	0.01	38.20	0.01	44.61	1.86	45.01	4.42
Segment 2	27.91	0.01	27.91	0.02	31.83	1.25	32.54	5.85
Segment 3	56.20	0.01	56.20	0.01	62.56	1.63	62.32	0.47
Segment 4	62.20	0.00	62.20	0.01	66.28	1.37	65.46	0.57
Segment 5	39.20	0.00	39.20	0.01	42.85	0.81	42.35	0.43
Segment 6	38.20	0.01	38.20	0.01	41.80	0.72	42.00	0.91
Segment 7	39.19	0.01	39.20	0.01	42.71	0.80	42.50	0.53
Segment 8	56.40	0.02	56.40	0.02	60.63	1.00	60.56	0.84
Segment 9	61.89	0.01	62.03	0.02	66.42	2.17	65.92	0.90
Segment 10	79.42	0.01	79.42	0.02	83.05	1.65	82.77	0.73
Segment 11	45.19	0.01	45.20	0.01	49.54	1.15	48.84	1.23
Segment 12	45.59	0.02	45.59	0.02	49.39	1.18	52.73	22.00
Segment 13	34.92	0.02	34.92	0.02	38.70	0.78	38.21	0.63
Segment 14	20.04	0.01	20.04	0.01	20.04	0.01	20.04	0.01

The introduction was tailored for the four conditions, focusing on the aim of the lesson and specific use aspects (e.g., the narration asked the VR groups to look around and guided the segmented groups on how to use their interaction modality). The durations for the segmented groups include the content presentation and the time the user took to start the subsequent segment. Segment 14 concluded seamlessly without interaction for the segmented groups (a prompt asked the VR groups to remove their HMD), resulting in similar durations over all conditions

The small differences of 0.01 to 0.05 in SD resulted from small dissimilarities in the loading times caused by the real-time execution of the compiled Unity applications and the time resolution of the logged time stamps. Discrepancies in the sums are due to rounding to two decimal places

Table 3 Means, Standard Deviations, and two-way ANOVA statistics for knowledge

Variable	Segmentation				ANOVA		
	Continuous		Segmented				
	M	*SD*	*M*	*SD*	Effect	*F*(1, 126)	η^2_p
Objective Knowledge							
MT: 2D video	6.50	1.81	5.97	1.62	MT	1.21	0.01
MT: HMD VR	6.30	1.38	5.55	1.60	**Segmentation**	**5.21***	**0.04**
					MT × segmentation	0.16	0.00
Subjective Knowledge Gain (Ritzmann et al. 2014)							
MT: 2D video	5.80	0.98	5.57	1.28	MT	3.90	0.03
MT: HMD VR	5.13	1.40	5.41	1.09	Segmentation	0.02	0.00
					MT × segmentation	1.48	0.01

n = 130. ANOVA, analysis of variance; MT, media type; HMD VR, head-mounted display virtual reality

Bolded values indicate statistical significance (**p* <.05)

Table 4 Means, Standard Deviations, and Two-Way ANOVA statistics for cognitive load

Variable	Segmentation				ANOVA		
	Continuous		Segmented				
	M	*SD*	*M*	*SD*	Effect	*F*(1, 126)	η^2_p
ICL (Leppink et al. 2014)							
MT: 2D video	3.43	1.55	3.36	1.25	MT	0.34	0.00
MT: HMD VR	3.41	1.33	3.66	1.29	Segmentation	0.14	0.00
					MT × Segmentation	0.45	0.00
ICL (Klepsch et al. 2017)							
MT: 2D video	3.61	1.61	3.55	1.41	MT	0.50	0.00
MT: HMD VR	3.15	1.33	3.65	1.34	Segmentation	0.77	0.01
					MT × Segmentation	1.27	0.01
ECL (Leppink et al. 2014)							
MT: 2D video	1.72	0.70	1.69	0.79	MT	0.25	0.00
MT: HMD VR	1.80	1.02	1.76	0.79	Segmentation	0.06	0.00
					MT × Segmentation	0.00	0.00
ECL (Klepsch et al. 2017)							
MT: 2D video	2.25	1.02	2.00	0.91	MT	3.29	0.03
MT: HMD VR	2.34	1.43	2.65	1.21	Segmentation	0.02	0.00
					MT × Segmentation	1.84	0.01
GCL (Leppink et al. 2014)							
MT: 2D video	5.20	1.02	5.10	0.83	**MT**	**4.85***	**0.04**
MT: HMD VR	4.73	1.08	4.77	1.18	Segmentation	0.02	0.00
					MT × Segmentation	0.15	0.00
GCL (Klepsch et al. 2017)							
MT: 2D video	5.02	1.10	4.93	1.19	**MT**	**4.32***	**0.03**
MT: HMD VR	4.35	1.41	4.70	1.19	Segmentation	0.33	0.00
					MT × Segmentation	1.03	0.01

n = 130. ANOVA, analysis of variance; ICL, Intrinsic Cognitive Load; ECL, Extraneous Cognitive Load; GCL, Germane Cognitive Load; MT, media type; HMD VR, head-mounted display virtual reality

Bolded values indicate statistical significance (**p*<.05)

3.6 Effects of media type and segmentation on technology acceptance

We analyzed the three core constructs of the TAM. No main effects or interactions between display type and segmentation were found for PU, PEOU, or BI. Given the seven-point Likert scale, participants in the four experimental groups rated the three core technology acceptance constructs as high (Table 6).

We finally examined the associations of Interest/Enjoyment with the three measured TAM constructs: PU, PEOU, and BI. For the 2D video groups, Interest/Enjoyment showed a strong positive correlation with PU at $r_s(62) = 0.54$, $p < 0.001$, and BI at $r_s(62) = 0.52$, $p < 0.001$, as well as a small correlation with PEOU at $r_s(62) = 0.25$,

Table 5 Means, Standard Deviations, and two-way ANOVA statistics for Interest/Enjoyment

Variable	Segmentation				ANOVA		
	Continuous		Segmented				
	M	*SD*	*M*	*SD*	Effect	*F*(1, 126)	η^2_p
Interest/Enjoyment							
MT: 2D video	5.88	0.82	5.91	0.64	MT	1.02	0.01
MT: HMD VR	5.95	0.79	6.12	0.96	Segmentation	0.47	0.00
					MT × Segmentation	0.22	0.00

n = 130. ANOVA, analysis of variance; MT, media type; HMD VR, head-mounted display virtual reality

Table 6 Means, Standard Deviations, and two-way ANOVA statistics for technology acceptance

Variable	Segmentation				ANOVA		
	Continuous		Segmented				
	M	*SD*	*M*	*SD*	Effect	*F*(1, 126)	η^2_p
TAM PU							
MT: 2D video	5.89	1.19	5.56	1.27	MT	1.16	0.01
MT: HMD VR	5.47	1.54	5.47	1.41	Segmentation	0.47	0.00
					MT x Segmentation	0.47	0.00
TAM PEOU							
MT: 2D video	5.73	1.22	6.04	1.05	MT	0.07	0.00
MT: HMD VR	5.92	1.14	5.95	1.04	Segmentation	0.81	0.01
					MT x Segmentation	0.49	0.00
TAM BI							
MT: 2D video	6.01	1.39	6.00	1.01	MT	0.46	0.00
MT: HMD VR	5.72	1.55	5.98	1.27	Segmentation	0.30	0.00
					MT x Segmentation	0.35	0.00

n = 130. ANOVA, analysis of variance; TAM, Technology Acceptance Model; PU, Perceived usefulness; PEOU, Perceived Ease of Use; BI, Behavioral Intention; MT, media type; HMD VR, head-mounted display virtual reality

$p = 0.050$. Additionally, for HMD VR groups, strong positive correlations with PU at $r_s(64) = 0.60, p < 0.001$, and with BI at $r_s(64) = 0.53$, $p < 0.001$, as well as a medium correlation with PEOU at $r_s(64) = 0.36$, $p = 0.003$ were computed.

4 Discussion

We evaluated the potential benefits of immersive VR for learning with high ecological validity and relevance to the organizational context. We developed a multimedia lesson as 2D video and HMD VR module for airport security officers to give them introductory training on 3D CT technology and processes for baggage screening that were introduced at their airport. We studied the effects of media type (2D video vs. HMD VR) and segmentation (continuous vs. segmented) on different dependent variables: post-training Objective Knowledge and Subjective Knowledge Gain, aspects of CL, Interest/Enjoyment, and technology acceptance. The hypotheses and results are summarized in Table 7. Contrary to previous findings, we found that segmenting the multimedia lesson led to significantly lower Objective Knowledge scores in the post-training test than in continuous instruction. While no statistically significant difference was found for Objective Knowledge by media type, learning with 2D video led to significantly higher GCL scores than with HMD VR. No significant effects were found for ICL or ECL. Nevertheless, the CL scales by Leppink et al. (2014) and Klepsch et al. (2017) yielded comparable results. No significant effects were found for media type or segmentation on the Interest/Enjoyment and TAM variables. However, we found strong correlations between Interest/Enjoyment and PU, as well as between Interest/Enjoyment and BI, which is in line with the literature. In the following sections, we discuss these results in the context of relevant literature before addressing limitations and further research and concluding remarks.

4.1 Segmentation influences Objective Knowledge

The experimental groups showed significantly higher Objective Knowledge scores than the control group. These results support hypothesis 1, which was that the multimedia lesson created provides participants with introductory information about 3D CT imaging systems aiding airport security screeners in acquiring new knowledge. Learners experiencing the continuous multimedia lesson achieved significantly higher Objective Knowledge scores than learners experiencing the learning content in segmented conditions. This result does not support our hypothesis 2 and also

Table 7 Hypotheses and results

No	Hypothesis	Result
1	Objective knowledge: experimental groups > control group	Confirmed
2	Objective knowledge: continuous < segmented	Rejected; opposite effect
3	ICL: continuous > segmented	Rejected; not significant
4	ECL: 2D video < HMD VR	Rejected; not significant
5	ECL: continuous < segmented	Rejected; not significant
6	GCL: 2D video > HMD VR	Confirmed
7	GCL: continuous < segmented	Rejected; not significant
8	Interest/enjoyment: 2D video < HMD VR	Rejected; not significant
9a	Interest/enjoyment correlates with PU in 2D video condition	Confirmed
9b	Interest/enjoyment correlates with PU in HMD VR condition	Confirmed
10a	Interest/enjoyment correlates with BI in 2D video condition	Confirmed
10b	Interest/enjoyment correlates with BI in HMD VR condition	Confirmed

ICL, Intrinsic Cognitive Load; ECL, Extraneous Cognitive Load; GCL, Germane Cognitive Load; HMD VR, head-mounted display virtual reality; PU, Perceived Usefulness; BI, Behavioral Intention

previous findings reported in a number of studies (e.g., Boucheix and Guignard 2005; Hasler et al. 2007; Moreno 2007; Parong and Mayer 2018). A possible reason for our result may be that learners with higher levels of prior knowledge of a subject matter do not benefit from segmenting the learning material to the same degree as learners with little or no prior knowledge or might even be hampered by segmentation (Boucheix and Guignard 2005; Spanjers et al. 2010). However, this does not seem plausible for our sample due to several reasons: First, our participants did not have prior experience of 3D CT baggage screening. Second, the control group in our study answered only about half of the Objective Knowledge questions correctly, which indicates limited prior knowledge. Third, participants rated their Preknowledge of 3D CT technology as rather low ($M = 2.54$ across all participants; 7-point Likert scale). Moreover, one could also argue that contextual knowledge may have been substantial enough to influence the effectiveness of segmentation and thereby result in our finding that continuous conditions resulted in higher objective knowledge than the segmented conditions. When comparing media types, our results did not yield a significant effect on Objective Knowledge. This means that in our study, the use of HMD VR did not result in superior acquisition of factual, conceptual, and procedural knowledge compared to 2D video. This may be attributed to the technology's high interaction and display fidelity, which may negatively influence learners' attention (Parong and Mayer 2020). Our findings align with those of previous studies (e.g., Webster 2016; Makransky et al. 2019a, 2021; Parong and Mayer 2020; Baceviciute et al. 2022), which underscore the complex interplay of media types and learning processes. Analogous to Makransky et al. (2019b), we did not find a significant difference in Subjective Knowledge Gain when learning with HMD VR compared to video on a 2D display screen. Similarly, no significant difference in Subjective Knowledge Gain was found when comparing the continuous and segmented lessons.

4.2 Media type influences Germane Cognitive Load

Our hypothesis 6 was confirmed, learners reported higher GCL when experiencing a multimedia lesson as video on a 2D screen display (low interaction and display fidelity) than when experiencing a lesson with HMD VR (high interaction and display fidelity). Based on the traditional view of GCL, the results indicate that participants in the 2D video groups invested more cognitive resources in constructing, processing, and automating mental models or schemas than those in the HMD VR groups (Klepsch et al. 2017; Klepsch and Seufert 2020). Interestingly, similar results have been found for the scale of Leppink et al. (2014). Following the reconceptualized notion of GCL, for which we did not formulate a hypothesis due to a lack of studies, our findings suggest that more germane cognitive resources were allocated to deal with the complexity of the learning material (Leppink et al. 2014). However, no statistically significant differences in GCL scores were found on segmentation, which rejects hypothesis 7. The ICL did not differ significantly for either IV or either instrument. While these findings are in line with the literature on media type and therefore emphasize the similarly perceived difficulty of the learning material by the participants of our study, they are not consistent with hypothesis 3 formulated for segmentation. Perhaps participants in our study had no need for the learning material to be segmented to reduce its complexity and aid in managing ICL (e.g., Mayer and Moreno 2010; Noetel et al. 2022). Regarding ECL, the mean scores for the instruments by Leppink et al. (2014) and Klepsch et al. (2017) were low on all conditions ($M \leq 2.65$ on a 7-point Likert scale). Parong and Mayer (2020) argued that HMD VR (with the possibility to look around and interact with 3D objects), along with extraneous sounds and animations, is linked to moving attention away from the instructional material, thus increasing ECL. Interestingly, our findings do not show a significant main effect on media type, rejecting hypothesis 4. In our study, we considered recommendations for instructional design (Mayer 2021) in the multimedia lesson (which may also explain the generally low ECL values), kept aspects of sound and instructional animations constant for all conditions, limited active exploration, and did not allow for complex interactions with objects. Furthermore, against our hypothesis 5 (based on the assumption that increased control and agency may negatively influence ECL; Makransky et al. 2019b, 2021), our user interactions to control learning segments have not induced significantly higher ECL. This may be due to its easy-to-use implementation (pressing a button with a computer mouse or using a VR controller, respectively).

4.3 Strong correlations between Interest/Enjoyment and technology acceptance

We found no significant effects of media type (2D video vs. HMD VR) and segmentation (continuous vs. segmented lesson) on Interest/Enjoyment (thus, rejecting hypothesis 8) and technology acceptance. This could be due to ceiling effects (e.g., Austin and Brunner 2003) for all experimental conditions (on a Likert scale ranging from 1 to 7; Interest/Enjoyment: $M \geq 5.88$; PU: $M \geq 5.47$; PEOU: $M \geq 5.73$; BI: $M \geq 5.72$). As this study focused on outcome variables suited for organizational and professional settings rather than those suited for the educational sector, as numerous studies have before (Radianti et al. 2020; Wu et al. 2020; Di Natale et al. 2020; Pellas et al. 2021; Hamilton et al. 2021; Villena-Taranilla et al. 2022; Coban et al. 2022; Rojas-Sánchez et al. 2023), our findings illustrate the complexity of professional contexts. However, our data supports hypotheses 9a and 10a (for 2D video; PU, BI, respectively) as well as 9b and 10b (for HMD VR; PU, BI, respectively) for a strong relationship between Interest/Enjoyment and the core TAM constructs reported in recent literature. We found a strong positive correlation for both media types: between Interest/Enjoyment and PU, as well as between Interest/Enjoyment and BI. Furthermore, a medium positive correlation was found between Interest/Enjoyment and PEOU for 2D video as well as for HMD VR.

4.4 Comparable cognitive load scales of Leppink et al. (2014) and Klepsch et al. (2017)

When comparing the instruments by Leppink et al. (2014) and Klepsch et al. (2017) for measuring and interpreting ICL, ECL, and GCL, our results show moderate to strong positive correlations for all three types of CL. Additionally, our findings on CL do not provide evidence for the theoretically argued benefit of the traditional understanding of CL with the instrument proposed by Klepsch et al. (2017). Furthermore, one scale of each instrument computes in low reliability. These findings are worth following up in future research. They indicate that both instruments may be employed independently of which understanding of CL is adopted (cf. Duran et al. 2022; Krieglstein et al. 2022). While Klepsch et al. (2017) argue that their instrument reliably measures the three-factor structure of CL and is easier to adopt than the scales of Leppink et al. (2014), we are in agreement with Klepsch et al. (2017) that both questionnaires should be considered to advance theory building of CL (see also Sweller 2023; Martella et al. 2024).

4.5 Practical implications

In line with previous studies (Makransky et al. 2019a; Zhao et al. 2020; Makransky and Klingenberg 2022), our data suggest that HMD VR sparks Interest/Enjoyment in learners as well as high technology acceptance scores. This can be favorable, especially when instruction aims to motivate and excite learners about new subject matter. However, suppose that the organizational status quo does not yet include state-of-the-art learning media or technology. In this case, similar positive effects may be produced by the introduction of other, less novel, or immersive learning media, as the high scores for Interest/Enjoyment and TAM constructs for 2D videos show. Moreover, our results indicate that 2D video experiences are more cost-effective and offer greater utility when the goal is to convey declarative and procedural knowledge to employees.

Regarding segmentation, our study neutralizes the notion that simply adding a design measure, such as segmenting learning content, will benefit learning outcomes, as suggested by previous studies (e.g., Mayer et al. 2018). This underlines the importance of further advancing the understanding of the effectiveness of CTML principles (Mayer 2021) for HMD VR, as their application with current VR technology needs further research (Çeken and Taşkın 2022). Therefore, instructional designers should carefully consider instructional goals, multimedia parameters, and learners' characteristics when implementing such a design principle to maximize educational value. It may be favorable to use continuous lessons for learners with high levels of prior knowledge (e.g., Tobias 1994; Dochy et al. 1999; Hailikari et al. 2008; Spanjers et al. 2011; Delgado and Mayer 2025) or when conveying knowledge through a novel medium (Ahn et al. 2022; Klingenberg et al. 2022).

4.6 Limitations and future research

Considering our results, the instructional content of our multimedia lesson was manageable in complexity, given the screeners' prior implicit knowledge and expertise in the context of airport security. On the one hand, however, the content covered a wide range of the knowledge dimensions specified by Anderson et al. (2001): factual, conceptual, and some procedural knowledge. On the other hand, our final version of the Objective Knowledge test mainly focused on remembering and understanding, which are only the first two levels according to the cognitive process dimensions of Anderson et al. (2001; 1. remember, 2. understand, 3. apply, 4. analyze, 5. evaluate, 6. create). Thus, evaluating the effects of media type and segmentation with more advanced learning content and knowledge items covering higher cognitive processes would be interesting. In addition, we examined only an introductory multimedia lesson (the actual learning content was delivered in under 11 min); it would be interesting to determine in a study analogous to ours what effect the duration of lessons and learning segments has on learning outcomes, cognitive and affective aspects, and technology acceptance. We argued that the multimodal richness (specifically high interaction and display fidelity) provided by HMD VR and the control interactions in the segmented groups would lead to higher ECL (hypothesis 4, 5). However, our current data and analyses do not show such effects. To further explore this aspect, conducting follow-up experiments with conditions varying in levels of multimodal richness (e.g., still images instead of animations) and implementing only distinct aspects of fidelity would allow a better understanding from a scientific point of view. To keep the learning experience conditions comparable, we did not implement any complex interactions other than controlling the start of the next learning segment (for the segmented conditions only). However, a key feature of immersive VR with tracked hand input devices (cf. Kim et al. 2020) is the ability to explore and naturally interact with the virtual environment (e.g., Spittle et al. 2023). Our findings for HMD VR are transferable to VR experiences in professional contexts with high interactivity and display fidelity (e.g., looking around, stereoscopic display) but not necessarily to applications that allow active exploration and interaction with objects in the virtual environment. Thus, evaluating such interactions embedded in the instructional design would allow a better understanding of these effects. Based on our findings, it could be argued that the basic interactions implemented in our study hinder acquiring simple, declarative knowledge. Accordingly, a noteworthy research question would be whether alternative forward commands (e.g., with a click on a keyboard, by voice command) would be more beneficial by potentially reducing extraneus cognitive load and enhancing the efficiency of declarative knowledge acquisition. Since we evaluated knowledge acquisition immediately after the presentation of the learning content, it would also be interesting to see how our narrative, context-rich multimedia lessons would perform for knowledge retention (e.g., after several weeks; Lovreglio et al. 2021) and knowledge transfer (cf., Calvert and Hume 2023), as well as when embedded in a broader didactic approach (e.g., Buchner 2023). Finally, since a possible explanation for the high values of Interest/Enjoyment or technology acceptance scores (presumed ceiling effects) could be related to a generally high interest in new learning technologies in our specific sample (given the voluntary nature of participation), further studies in the practical field would be valuable.

5 Conclusion

In a 2 × 2 between-subjects design, we evaluated the effects of media type (2D video vs. HMD VR; low vs. high interaction and display fidelity, respectively) and segmentation (continuous vs. segmented), with the learning content equivalent across all four conditions. Objective Knowledge was significantly higher for participants experiencing the learning content in the continuous conditions than for those in the segmented conditions. Regarding cognitive load, we observed a main effect of the media type: Users experiencing the multimedia lesson as a 2D video rated GCL significantly higher than with HMD VR; similar for both scales aiming to assess distinct CLs. Depending on the understanding of GCL, this finding indicates that learners in 2D video groups either invested more germane cognitive resources for the formation and regulation of mental models and schemas (scale by Klepsch et al. 2017) or to deal with the complexity of the learning material than those in the HMD VR groups (scale by Leppink et al. 2014). Further exploratory evaluations revealed moderate to strong correlations between two widely applied CL survey instruments (Leppink et al. 2014; Klepsch et al. 2017) despite their partly different conceptualizations. However, we did not find significant effects of the media and segmentation types on Subjective Knowledge Gain, Interest/Enjoyment, and the core TAM (Venkatesh and Bala 2008) constructs (PU, POEU, BI). Nevertheless, strong correlations were found between Interest/Enjoyment and PU, as well as between Interest/Enjoyment and BI, supporting the current literature on technology acceptance. These results provide valuable insights for the practical implementation of instructional VR applications and highlight the need for further evaluation of learning applications utilizing current VR technology.

Appendix

See Table 8.

Table 8 Subjective rating scales used in the current study

Scale	English	German translation (used in the current study)
Self-rated prior knowledge (cf. Moreno and Mayer 1999, p. 361)		
Preknowledge	I know the technological developments from the first X-ray scanners to 3D CT machines	Ich kenne die technologischen Entwicklungen von den ersten Röntgenscannern bis hin zu 3D-CT-Maschinen
Preknowledge	I know the functioning of 3D CT technology	Ich kenne die Funktionsweise von 3D-CT-Technologie
Preknowledge	I know the software functions of 3D CT technology for the area of cabin baggage screening	Ich kenne die Softwarefunktionen von 3D-CT-Technologie für den Bereich der Handgepäckkontrollen
Simulator sickness (cf. Chang et al. 2021, p. 4)		
Simulator sickness	Did you experience discomfort from the learning system at any time during the experience? *If yes:* Please describe your discomfort	Haben Sie während des Erlebnisses zu irgendeinem Zeitpunkt Unwohlsein durch das Lernsystem verspürt? *Falls ja:* Bitte beschreiben Sie Ihr Unwohlsein
Training evaluation inventory (Ritzmann et al. 2014, p. 68); both English and German translations are provided in the original literature		
Subjective knowledge gain	I have the impression that my knowledge has expanded on a long-term basis	Ich habe den Eindruck, mein Wissen hat sich langfristig erweitert
Subjective knowledge gain	I will be able to remember the new themes well	Ich werde mir die neuen Themen gut merken können
Subjective knowledge gain	I think that I will still be able to report what I learned some time after [the learning unit]	Ich denke, ich werde auch einige Zeit nach [der Lerneinheit] noch berichten können, was ich gelernt habe
Cognitive load (Leppink et al. 2014, p. 37)		
Intrinsic cognitive load	The content of [this learning unit] was very complex	Der Inhalt [dieser Lerneinheit] war sehr komplex
Intrinsic cognitive load	The problems covered in [this learning unit] were very complex	Die behandelten Themen in [dieser Lerneinheit] waren sehr komplex
Intrinsic cognitive load	In [this learning unit], very complex terms were mentioned	In [dieser Lerneinheit] wurden sehr komplexe Ausdrücke erwähnt
Intrinsic cognitive load	I invested a very high mental effort in the complexity of [this learning unit]	Ich investierte sehr viel mentale Anstrengung in die Komplexität [dieser Lerneinheit]
Extraneous cognitive load	The explanations and instructions in [this learning unit] were very unclear	Die Erklärungen und Anweisungen in [dieser Lerneinheit] waren sehr unklar
Extraneous cognitive load	The explanations and instructions in [this learning unit] were full of unclear language	Die Erklärungen und Anweisungen in [dieser Lerneinheit] waren voll von unklarer Sprache
Extraneous cognitive load	The explanations and instructions in [this learning unit] were, in terms of learning, very ineffective	Die Erklärungen und Anweisungen in [dieser Lerneinheit] waren, bezogen auf das Lernen, sehr ineffektiv
Extraneous cognitive load	I invested a very high mental effort in unclear and ineffective explanations and instructions in [this learning unit]	Ich investierte sehr viel mentale Anstrengung in unklare und ineffektive Erklärungen in [dieser Lerneinheit] investiert
Germane cognitive load	[This learning unit] really enhanced my understanding of the content that was covered	[Diese Lerneinheit] erweiterte mein Verständnis des behandelten Inhalts
Germane cognitive load	[This learning unit] really enhanced my understanding of the problems that were covered	[Diese Lerneinheit] erweiterte mein Verständnis der behandelten Themen
Germane cognitive load	[This learning unit] really enhanced my knowledge of the terms that were mentioned	[Diese Lerneinheit] erweiterte mein Wissen über die erwähnten Begriffe
Germane cognitive load	[This learning unit] really enhanced my knowledge and understanding of how to deal with the problems covered	[Diese Lerneinheit] erweiterte mein Wissen und Verständnis über den Umgang mit den behandelten Themen
Germane cognitive load	I invested a very high mental effort during [this learning unit] in enhancing my knowledge and understanding	Ich investierte sehr viel mentale Anstrengung während [dieser Lerneinheit] in das Erweitern meines Wissens und Verständnisses
Cognitive load (Klepsch et al. 2017, p. 10); both English and German translations are provided in the original literature		
Intrinsic cognitive load	For [this learning unit], many things needed to be kept in mind simultaneously	Bei [der Lerneinheit] musste man viele Dinge gleichzeitig im Kopf bearbeiten
Intrinsic cognitive load	[This learning unit] was very complex	[Diese Lerneinheit] war sehr komplex
Extraneous cognitive load	During [this learning unit], it was exhausting to find the important information	Bei [dieser Lerneinheit] ist es mühsam, die wichtigsten Informationen zu erkennen
Extraneous cognitive load	The design of [this learning unit] was very inconvenient for learning	Die Darstellung bei [dieser Lerneinheit] ist ungünstig, um wirklich etwas zu lernen
Extraneous cognitive load	During [this learning unit], it was difficult to recognize and link the crucial information	Bei [dieser Lerneinheit] ist es schwer, die zentralen Inhalte miteinander in Verbindung zu bringen
Germane cognitive load	I made an effort, not only to understand several details, but to understand the overall context	Ich habe mich angestrengt, mir nicht nur einzelne Dinge zu merken, sondern auch den Gesamtzusammenhang zu verstehen

Table 8 (continued)

Scale	English	German translation (used in the current study)
Germane cognitive load	My point while dealing with [this learning unit] was to understand everything correct	Es ging mir beim Bearbeiten [der Lerneinheit] darum, alles richtig zu verstehen
Germane cognitive load	[The learning unit] consisted of elements supporting my comprehension of [the learning material]	[Die Lerneinheit] enthielt Elemente, die mich unterstützen, [den Lernstoff] besser zu verstehen
Intrinsic motivation inventory (McAuley et al. 1991, p. 145; modified tense)		
Interest/enjoyment	I enjoyed doing [this learning unit] very much	[Die] absolvierte [Lerneinheit] hat mir sehr gefallen
Interest/enjoyment	[This learning unit] was fun to do	[Die Lerneinheit] hat Spass gemacht
Interest/enjoyment*	I thought this was a boring [learning unit]	Ich dachte dies war eine langweilige [Lerneinheit]
Interest/enjoyment*	[This learning unit] did not hold my attention at all	[Diese Lerneinheit] konnte meine Aufmerksamkeit gar nicht halten
Interest/enjoyment	I would describe [this learning unit] as very interesting	Ich würde [diese Lerneinheit] als sehr interessant beschreiben
Interest/enjoyment	I thought [this learning unit] was quite enjoyable	Ich dachte [diese Lerneinheit] war ziemlich unterhaltsam
Interest/enjoyment	While I was doing [this learning unit], I was thinking about how much I enjoyed it	Während ich [diese Lerneinheit] machte, dachte ich darüber nach, wie sehr sie mir gefiel
Technology acceptance model (Venkatesh and Bala 2008, pp. 313–314)		
Perceived usefulness	Using [the learning medium] would improve my [learning performance]	Die Nutzung [des Lernmediums] würde meine [Lernleistung] verbessern
Perceived usefulness	Using [the learning medium] would increase my [learning productivity]	Die Nutzung [des Lernmediums] würde meine [Produktivität beim Lernen] erhöhen
Perceived usefulness	Using [the learning medium] would enhance my [learning effectiveness]	Die Nutzung [des Lernmediums] würde meine [Effektivität beim Lernen] erhöhen
Perceived usefulness	I find [the learning medium] would be useful for [learning]	Ich finde [das Lernmedium] wäre nützlich zum [Lernen]
Perceived ease of use	My interaction with [the learning medium] is clear and understandable	Der Umgang mit [dem Lernmedium] ist für mich klar und verständlich
Perceived ease of use	Interacting with [the learning medium] does not require a lot of my mental effort	Die Benützung [des Lernmediums] erfordert von mir keine grosse mentale Anstrengung
Perceived ease of use	I find [the learning medium] to be easy to use	Ich finde [das Lernmedium] ist einfach zu benutzen
Perceived ease of use	I find it easy to get [the learning medium] to do what I want it to do	Ich finde [das Lernmedium] macht ohne Probleme das, was ich möchte
Behavioral intention	Assuming I had access to [the learning medium], I intend to use it	Angenommen ich habe Zugang [zum Lernmedium], dann beabsichtige ich es zu nutzen
Behavioral Intention	Given that I had access to [the learning medium], I predict that I would use it	Wenn ich Zugang [zum Lernmedium] hätte, sage ich voraus, dass ich es nutzen würde
Behavioral intention	I plan to use [the learning medium] again in the coming months	Ich plane [das Lernmedium] in den kommenden Monaten wieder zu nutzen

Reverse-coded items are marked with an asterisk; formulations deviating from the original questionnaires of the authors mentioned are marked with square brackets

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Data availability The analyzed data of the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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